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**Natural human postural oscillations enhance the empathic response toward facial pain
expression of a computer-generated character.**

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Abstract

Virtual reality platforms producing interactive and highly realistic characters are increasingly used as a research tool in social and affective neuroscience, to better capture the dynamic of emotion communication, and the unintentional and automatic nature of emotional processes. Idle motion (i.e. non communicative movements) is a common ingredient used to create behavioral realism. However, its contribution to enhance the perception of emotion expressed by a CG character is critically lacking. Herein, healthy young adults were presented video clips of a CG character displaying a facial pain expression while its body was static (*still condition*) or while it was animated with natural postural oscillations (*idle condition*). Results showed a higher *empathic response* for the CG character's pain in the presence of natural postural oscillations. Indeed, participants perceived its facial pain expression as more intense (*experiment 1*) and reported to be more affected by its pain expression (*experiment 2*) in the *idle condition* than in the *still condition*. This study is the first to demonstrate the rule of biological motion in emotion perception research when kinematic doesn't contain socially relevant information. Future investigations will help to determine to what extent biological idle motion may be a key ingredient to guarantee the quality of human-machine interactions.

Keywords

Biological idle motion, Empathy, Pain perception, Virtual character, Behavioral realism

1. Introduction

Do you remind your reaction when meeting a street artist simulating a statue ? Perhaps, you were looking carefully to detect blinking and small variations in head or body posture, because you were wondering whether he was a human person or a stone character. These subtle movements are usually ‘neglected’ in social interactions, except in such a situation where the humanness of the person is ambiguous. In particular, this anecdote illustrates how much these non-communicative movements - coined *idle motion* by Egges and collaborators (Egges et al., 2004) - may be a core ingredient when animating a computer-generated (CG) character talking or expressing a dynamical facial expression, and used as a research tool to study emotion communication in humans (i.e. emotion recognition, empathy, emotional contagion, etc.). The usefulness of CG characters to create a more ecological interaction, while keeping a high control of the interaction is well accepted (de Gelder et al., 2018; Egges et al., 2004; Pan & Hamilton, 2018; Wykowska et al., 2016). The actual issue is not necessarily to create a fully interactive virtual character, but rather a character enough realistic, so that participants would accept that it may behave like a real person, such as feeling and expressing emotions. Indeed, its emotion must be judged as ‘believable’, and must provoke a spontaneous and socially expected reaction from participants, in order to capture the unintentional and automatic nature of emotional processes (de Gelder et al., 2018).

Yet, a CG character with a frozen body may be spontaneously perceived as a stone character rather than a virtual social partner. This inconsistency between a fixed body and a dynamical face would cause a feeling of eeriness towards the virtual agent, and then, may hinder the ‘expected’ interaction with it. Thus, *idle motion* is generally implemented by default on CG characters to increase their behavioral realism (Groom et al., 2009), or in a neutral (control) condition to make the CG character ‘alive’, without introducing confusing factors

(Buisine et al., 2014; de Melo et al., 2010; Krämer et al., 2018). *Idle motion* includes a *varied range of features such as subtle variations or shift in body posture caused by small muscle contraction, eye movements or blinking, breathing* (Egges et al., 2004; Kocoń, 2013). For instance, in Groom and collaborators, the conversational agent “blinked and moved her eyes in a natural fashion”. In de Melo et al. (2010), the agent in the control condition of the experiment 2 “displays a neutral respiration”. And in Krämer et al. (2018), “the virtual human did not show any kind of feedback but merely slight and randomized posture shifts and eye blinking in order to appear alive (idle behavior)”. Surprisingly, except our recent study (Treal et al., 2020), there is no empirical evidence supporting that these subtle movements may influence the perception of emotions expressed by a CG character. Treal and collaborators (2020) demonstrated that the facial pain expression of a virtual character was perceived as more intense and more believable when a subtle to-and-fro movement mimicking human dynamic equilibrium (postural oscillations) was added to its trunk, compared with a static condition. Although the method was artificial (i.e. the movement was manually implemented into the animation software), these results encouraged to further explore how much *idle motion* may contribute to make facial expression of a virtual person more believable.

The present study aimed to extend this seminal work, by using a new and ecological paradigm based on motion capture to reproduce natural postural oscillations to a virtual character. This method enabled to capture the complex pattern of body movements reflecting postural oscillations, and in particular, to take into account respiratory movements which are closely linked to postural control (Hunter & Kearney, 1981). Moreover, a recent study showed that visual attention was more sensitive to biological rather than mechanical motion, whether it was implemented on a human or a virtual body (Williams et al., 2019). In line with this work, biological movement seems critical to elicit at first glance the acceptance that a CG character may ‘feel’ like a real person. While idle motion was usually generated using algorithms (Egges

et al., 2004; Kocoń, 2013) or a hybrid system that combines motion capture data with procedural motion generation (Luo, Kipp & Neff, 2009), to our knowledge, this is the first study to ecologically implement unconstrained, natural human postural oscillations to a CG character coupled with dynamical facial expression.

Such a work is of great interest considering the growing number of platforms using virtual patients in serious games to improve clinical reasoning skills in healthcare professionals (Blanié et al., 2020; Dukes et al., 2012; Wang et al., 2016; Wu et al., 2014), or as a therapeutic tool with clinical populations showing social cognition deficits (Brunet-Gouet et al., 2016). For instance, by improving a CG character's anthropomorphism, a higher affective reaction may be elicited toward its pain, which may be sought to train emotional regulation in healthcare professionals. Empathy, which refers to the ability to share and understand others emotion or thinking, and feel motivated to help (Decety & Cowell, 2014), is critical in medical care. Especially, empathy for pain is probably naturally developed among caregivers. However, empathy implies a mechanism of *affective resonance*, i.e. an automatic sharing of other's state (Decety & Jackson, 2004; Jackson, Eugène, et al., 2015), resulting in the sense of mixed emotions (e.g. distress, sympathy) when facing pain in others (Decety, 2011; Decety & Fotopoulou, 2015; Goubert et al., 2005). In other terms, one can not remain insensitive to other people's suffering, and it may be challenging to both maintain compassionate care and cope with self-oriented unpleasant emotions provoked by emotionally distressing situations (Gleichgerricht & Decety, 2013, 2014; Shapiro, 2008). Thus, platforms using virtual patients appear as an innovative tool to help caregivers to better recognize their own emotional reactions and develop strategies enabling them to reduce emotional contamination.

It was hypothesized that these subtle movements (i.e. natural postural oscillations) would create the illusion that the CG character is alive, and thus would significantly influence

participants' *empathic response* toward its facial pain expression. As proposed by some authors, an *empathic response* refers to the outcome of two processes : *emotion identification* and *affect sharing* (Coll et al., 2017; see also Bird & Viding, 2014). Namely, a person would be considered empathic if he/she correctly identifies and shares other's emotion. These two interacting yet distinct facets of *empathic response* were assessed through two experiments : in *Experiment 1*, participants judged the intensity of a dynamical facial pain expression in a CG character, whose body was animated or not with these discrete movements. It was expected that pain in the virtual character would be perceived more intense in the *idle condition* compared with the *still condition*. Using the same material, *Experiment 2* aimed to determine whether participants reported more affective resonance (or sharing) when they were confronted to CG character's pain expression in the presence of idle motion, compared with a still condition. It was attempted that participants would be more affected by the character's pain expression when its body was animated with postural oscillations (*idle condition*) than in the *still condition*.

2. Experiment 1

2.1 Method

2.1.1 Participants

Thirty-two young adults from the Faculty of Sport Science of Paris-Saclay University took part in the experiment (mean age = 18.31 years, SD = 0.53, range = 18-19 years, 16 women). They were recruited through a course program which proposed on a voluntary basis to obtain one extra point on a test when participating in an experiment conducted in the laboratory. Every participant had or was corrected to normal vision. The study was approved

by the Ethics Committee of Paris-Saclay University (#CER-Paris-Saclay-2020-147) and participants gave written informed consent to take part in this study.

2.1.2. Material and Task

Stimuli were composed of ten video clips (duration = 4 seconds) displaying the upper body of a male virtual character (Figure 1) from the Empathy-Enhancing Virtual Evolving Environment (EEVEE) (Jackson, Michon, et al., 2015). The video clips were created with Blender® (BlenderFoundation, Amsterdam, Netherlands). The virtual character was animated with a dynamical facial pain expression at five different intensities (20%, 40%, 60 %, 80%, 100%), combined with body animation (*idle condition*, see below the section *Body Animation* for a detailed description of the method) or without body animation (*still condition*). The video clips are available online with a link at the section Supplementary material.

Facial pain expression Animation. The character's facial pain expression was created using the Action Units (AUs) according to the Facial Action Coding System (FACS) (Ekman & Friesen 1978). The characteristics AUs from the pain expression (AU4 (brow lower), AU6 (check raiser), AU7 (lid tighter), AU9 (nose wrinkle), AU10 (upper lip raiser) and AU43 (eyes closed)); and five occasionally AUs: AU12 (lip corner puller), AU20 (lip stretch), AU25 (lips part), AU26 (jaw drop) and AU27 (mouth stretch) (Prkachin, 1992)) were manipulated using Blender to create five intensities of facial expression (20%, 40%, 60%, 80%, 100% of their maximal contraction). Each video began with the character showing a neutral expression (sets of AUs at 0). The level of AUs linearly increased to reach the fixed intensity for 1 second. The pain expression was maintained 3 seconds until the end of the clip (Figure 1).



Figure 1 - Left figure: virtual character at the onset of the clip (neutral expression). Right figure: virtual character expressing pain (AUs recruited at 60% of their maximal contraction)

Body Animation. For the *idle motion condition*, the character's body was animated with pre-recorded human postural oscillations, i.e. subtle motion proper to dynamical human equilibrium and breathing. For the *still condition*, the character's body was fixed at the initial posture of the person in the pre-recorded motion capture sequence.

Session of motion capture : data were collected on a young man (age = 20, similar built than the male character). The person was instructed to “stand up naturally with his arms along the body without moving his feet” and to “look ahead”. Data were collected using motion capture system Qualisys (Göteborg, Sweden) with eight cameras at a frequency of 50Hz. Markers were placed on the following anatomical landmarks: head of the fifth and of the first metatarsal, medial and lateral malleolus, medial and lateral femoral condyles, anterior superior iliac spine, zyphoid process at the lower part of the sternum, L5, C7, nasion, acromion process, olecranon, processus styloideus of ulna and radius (Le Goic et al., 2018). Three markers were added to record respiratory movements : two on the sternal extremity of the clavicle and one

on the navel. Markers' positions were imported and applied on a skeleton to animate the virtual character using Blender® (BlenderFoundation, Amsterdam, Netherlands). The envelope of the character was mapped on the skeleton in Blender and the link between the envelope and the skeleton was fixed by the “automatic weighted” option available in Blender.

Judgement of Pain Intensity. The task was programmed using Psychopy (Peirce et al., 2019) and displayed on a computer screen (resolution = 1920 x 1080) at a viewing distance of 70 cm from participants. Each trial began with the presentation of a video clip (duration = 4 seconds). Following the video clip, the labels “Mild Pain” or “Very Intense Pain” [In French “Douleur peu intense” and “Douleur très intense”] were presented on each side of the screen. Participants had to judge the intensity of the virtual character's pain expression by clicking on one of the two labels. Each stimulus was displayed 10 times for a total of 100 trials for the task (10 trials * 5 facial expressions * 2 body conditions). The order of stimuli was randomized across the task. Every 20 trials, a pause screen was displayed and participants clicked on a rectangle centered on the screen to resume the task. Before the experimental phase, the participants performed a familiarization phase composed of 10 trials presenting each stimulus randomly.

2.1.3. Data analysis

The *Very Intense Pain* rating corresponding to the percentage of “Very Intense Pain” responses was calculated for each level of facial pain expression (20%, 40%, 60%, 80%, 100%) and the two body conditions (*still, idle*). All statistical analyses were performed using Python libraries (LMFIT (Newville et al., 2014) and SciPy (Virtanen et al., 2020)) and JASP (JASP Team, 2019).

Firstly, an ANOVA with repeated-measures was performed on *Very Intense Pain* rating with the intensity of facial expression (20%, 40%, 60%, 80%, 100%) and the body condition

(*still, idle*) as within-subject factors. In case of violation of sphericity assumption Greenhouse-Geisser correction was applied. A paired t-test was then performed on *Very Intense Pain* rating between the *idle* and *still* conditions, regardless the intensity of facial pain expression.

Secondly, a logistic function was fitted on *Very Intense Pain* rating for each participant using the formula: $y = 1/(1+\exp(-(x-PSE)/JND))$ in order to collect the Point of Subjective Equality (PSE) and the Just Noticeable Difference (JND) (see *Figure 2*). The PSE corresponded to the theoretical facial expression intensity for which a participant switched from “Mild Pain” to “Very Intense Pain” (i.e. the intensity of facial expression for which a participant responded 50% of the time “Very Intense Pain”). The JND informed about the precision of the categorization and corresponded to the minimal AUs contraction added to the PSE to provoke a quasi-systematic “Very Intense Pain” response. The *Very Intense Pain* rating of two participants did not fit the logistic analysis, so they were excluded from analysis. Thus, the final sample for the analysis on the psychophysical variables (PSE and JND) was composed of 30 participants. Paired t-tests were performed on PSE and JND to compare the perception of facial pain expression in *idle* vs. *still* conditions.

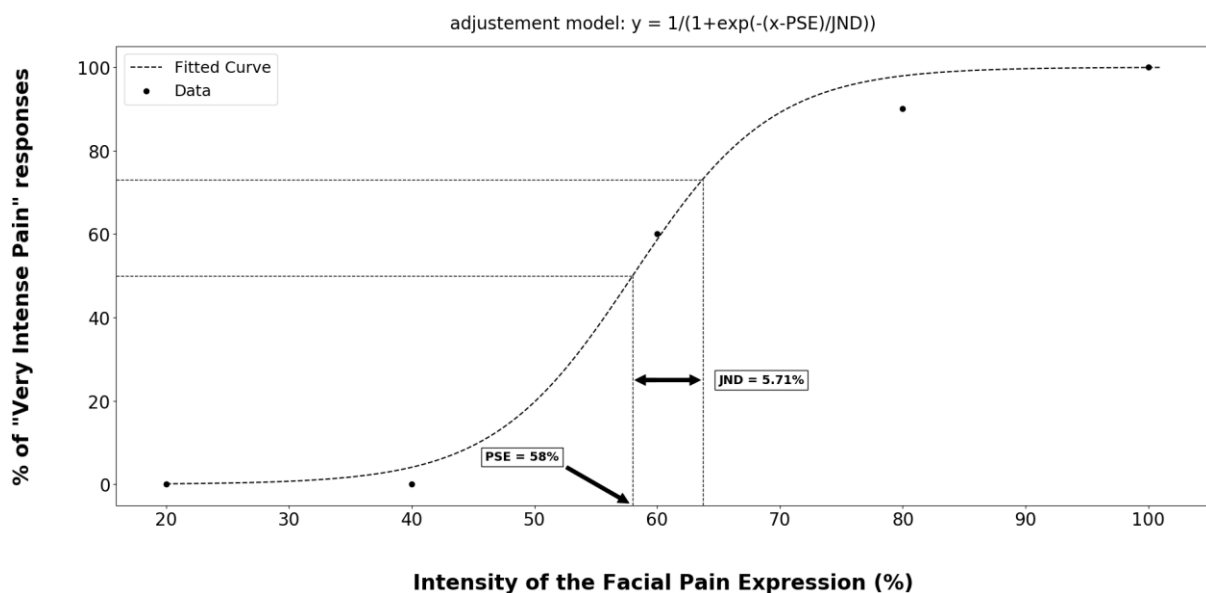


Figure 2 - Illustration of PSE and JND for one participant. There, the PSE = 58% indicates the theoretical intensity of facial pain expression for which this participant would respond at 50% of time "very intense pain". Above the PSE, participants judge the pain expression more often as "Very Intense Pain" than "Mild Pain". To make a difference between two intensities of facial expression for this categorization task, this participant needed at least a difference of 5.71% = JND.

2.2. Results

Repeated-measure ANOVA on *Very Intense Pain* rating revealed a main effect of the facial expression intensity [$F(2.1,65.0) = 196.23, p < .001, \eta^2 = .80$] and a main effect of the body animation [$F(1,31) = 4.91, p = .034, \eta^2 < .01$] but there was no significant interaction between these two conditions [$F(2.8,85.6) = 0.50, p = .666, \eta^2 < .01$]. Post-hoc tests with Bonferroni correction revealed that the percent of "Very Intense Pain" responses increases significantly with the intensity of the facial pain expression except between the intensity 20% and 40% (see *Table 1*) (mean responses for the intensity 20%, 40%, 60%, 80%, 100% = 3.3%, 13.3%, 60.8%, 95.6%, 99.5% respectively; 95% CIs [-1.4%, 8.0%], [4.5%, 22.0%], [49.2%, 72.4%], [92.7%, 98.5%], [99.0%, 100.1%] respectively). Paired t-test revealed that participants categorized significantly more often the pain expression as "Very Intense Pain" in the *idle* condition (mean proportion = 55.5 %, 95% CI [52.6%, 59.4%]) than in the *still* condition (mean proportion = 53.5 %, 95% CI [49.7, 57.3]) [$t(31) = 2.22, p = .034, d = .40$] (see *Figure 3*).

Table 1 – Pairwise comparisons for the perceived Intensity of the Facial Pain Expression

		Mean Difference	SE	t	Cohen's d	p_{bonf}

100%	20%	0.963	0.023	41.064	7.259	< .001
	40%	0.863	0.043	19.865	3.512	< .001
	60%	0.388	0.057	6.786	1.200	< .001
	80%	0.039	0.013	3.041	0.538	0.048
20%	40%	-0.100	0.047	-2.141	-0.378	0.403
	60%	-0.575	0.065	-8.826	-1.560	< .001
	80%	-0.923	0.026	-35.668	-6.305	< .001
40%	60%	-0.475	0.054	-8.823	-1.560	< .001
	80%	-0.823	0.043	-19.068	-3.371	< .001
60%	80%	-0.348	0.054	-6.504	-1.150	< .001

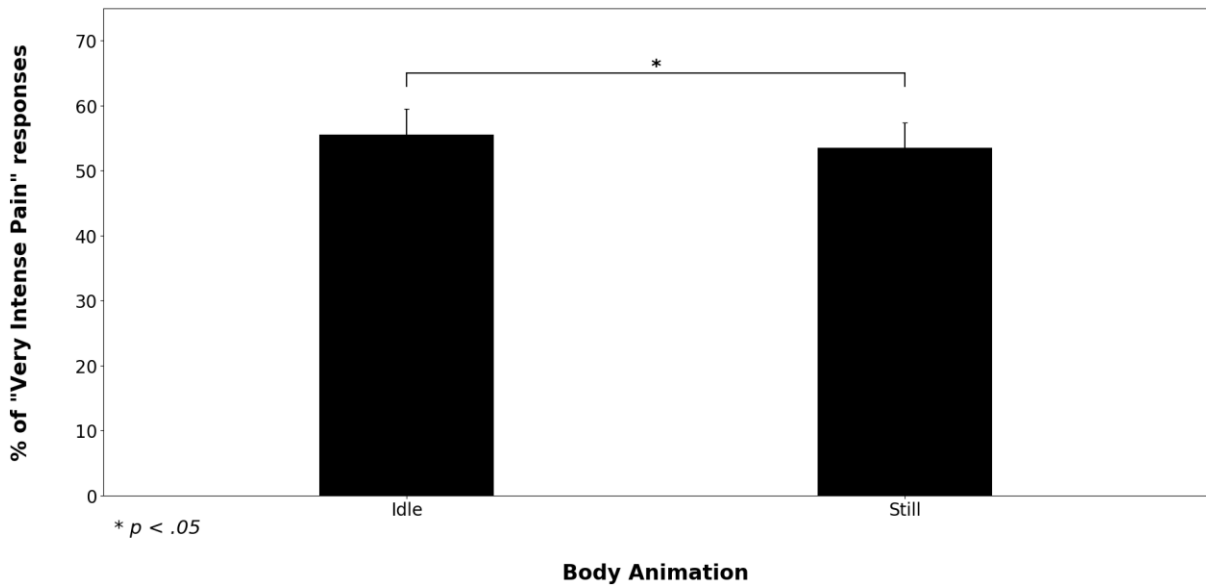


Figure 3 - Percent of “Very Intense Pain” responses in the still and idle conditions taking all facial expressions intensities together. Error bars correspond to the confidence intervals at 95%.

Paired t-test on PSE revealed a significant difference between the *idle* and *still conditions* [$t(29) = -2.22, p = .035, d = -.41$], which indicated that the intensity of facial pain expression was lower in the *idle condition* (PSE mean = 56.19%, 95% CI [52.59, 59.78]) than in the *still condition* to be categorized as “Very Intense” (PSE mean = 58.14%, 95% CI [54.31, 61.97]). Paired t-test on JND also revealed a significant difference between *idle* and *still conditions* [$t(29) = -2.24, p = .033, d = -.42$] indicating that participants were more precise for the intensity categorization in the *idle condition* (mean JND = 2.78%, 95% CI [1.57, 3.98]) than in the *still condition* (mean JND = 4.08%, 95% CI [2.46, 5.69]) (see *Figures 4 and 5*).

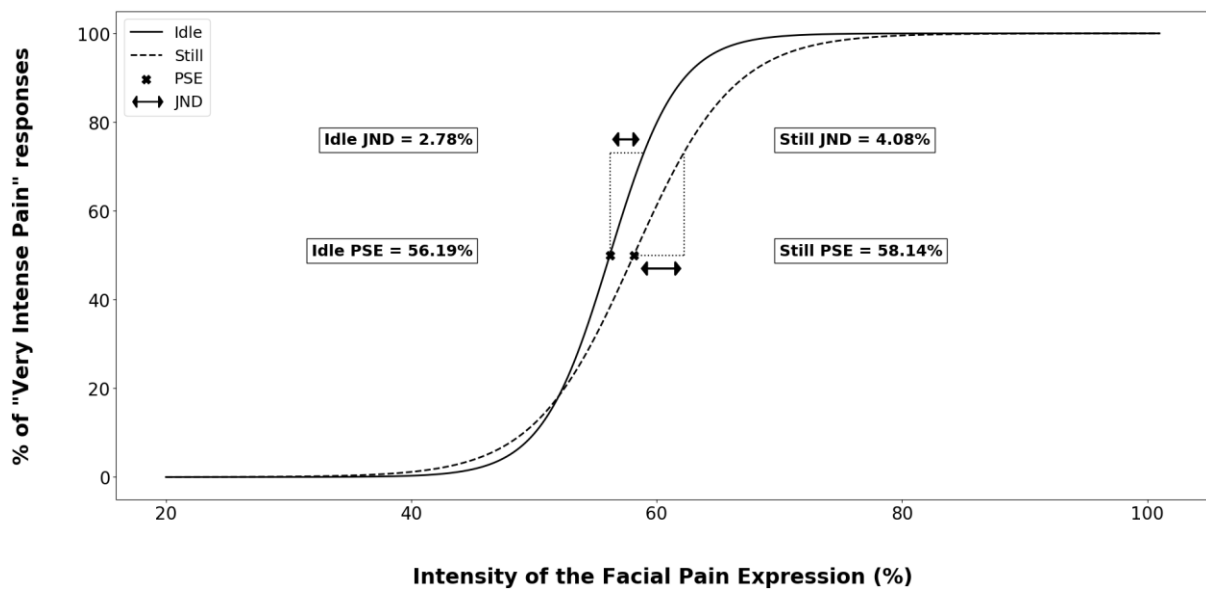


Figure 4 - Logistic modelling of “Very Intense Pain” responses according to facial pain expression intensity in the *still* and *idle conditions*. PSE and JND correspond to the mean of PSE and JND obtained from the modelling of each participant.

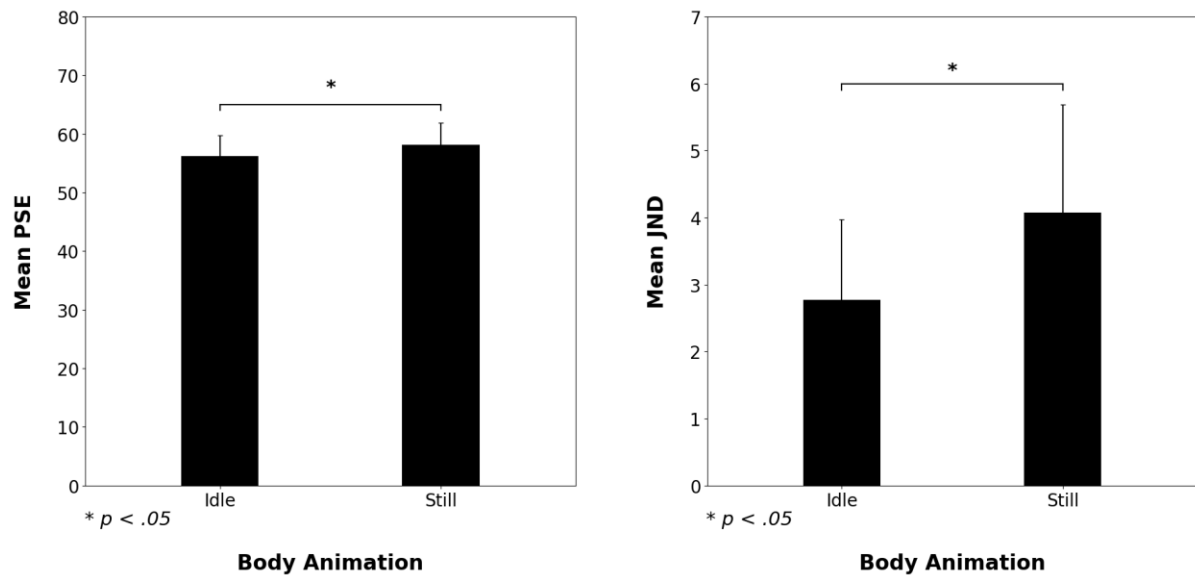


Figure 5 - Mean of PSE and JND obtained from the modelling of each participant in the *still* and *idle* conditions. Error bars correspond to the confidence intervals at 95%.

2.3 Summary

Results showed that the presence of *idle motion* influenced the perceived intensity of the CG character’s facial pain expression. Participants judged significantly more often its pain as “Very Intense Pain” in the *idle condition* compared with the *still condition*. Moreover, the logistic regression revealed a significantly lower PSE in the *idle condition*, indicating that a lower intensity of facial pain expression was necessary to be frequently categorized as a ‘Very intense Pain’ in the presence of postural oscillations compared with the *still condition*. The significantly lower JND in the *idle condition* compared with the *still condition* would suggest that a lower intensity of facial expression is needed to reach a quasi-systematic “Very Intense Pain” responses threshold in the presence of postural oscillations.

These results showed that the CG character's pain identification was modulated by the presence of postural oscillations, compared with a *still condition*. As these movements are non-communicative, it is likely that postural oscillations improved behavioral realism by creating the illusion that the virtual character is alive, which may increase its anthropomorphism and favor the perception of its pain expression.

3. Experiment 2

Experiment 2 aimed to examine whether adding natural human postural oscillations to the virtual character may enhance *affect sharing* when facing its pain expression. In contrast with Coll et al. (2017), this construct is not restricted to emotional contagion, yet it reflects an affective arousal in response to the valence and intensity of other's emotion. Consequently, *affect sharing* would elicit a varied range of feeling, including self-oriented (e.g. distress) or other-oriented affective responses (e.g., compassion, sympathy) (Goubert et al., 2005), notably depending on contextual and individual factors (e.g. individual capacity of emotion regulation). Concretely, *affect sharing* was assessed in *experiment 2* by asking participants to report whether or not they felt affectively arised (i.e. 'affected') when viewing pain in the virtual character. A higher subjective sense of *being affected* by the CG character's pain was attempted in the *idle condition* compared with the *still condition*.

3.2. Method

3.2.1. Participants

Thirty-four young adults from the Faculty of Sport Science of Paris-Saclay University took part in the experiment (mean age = 18.56 years, SD = 1.35, range = 18-25 years, 17 women). They were recruited through the same course program as for Experiment 1. Every participant had or was corrected to normal vision. The study was approved by the Ethics Committee of Paris-Saclay University (#CER-Paris-Saclay-2020-147) and participants gave written informed consent to take part in this study.

3.2.2. Material and Task

Self-report of affect-sharing. The same video clips than in the Experiment 1 were presented to participants. The task was programmed using Psychopy (Peirce et al., 2019) and displayed on a computer screen (resolution = 1920 x 1080) at a viewing distance of 70 cm from participants. Each trial began with the presentation of a video clip (duration = 4 seconds). Following the video clip, the labels “Not Affected” or “Affected” [In French “Pas Touché(e)” and “Touché(e)"] were presented on each side of the screen. Participants had to judge whether they were affected by the virtual character’s pain expression by clicking on one of the two labels. Each stimulus was displayed 10 times for a total of 100 trials for the task (10 trials * 5 facial expressions * 2 body conditions). The order of stimuli was randomized across the task. Every 20 trials, a pause screen was displayed and participants clicked on a rectangle centered on the screen to resume the task. Before the experimental phase, the participants performed a familiarization phase composed of 10 trials presenting each stimulus randomly.

3.2.3. Data Analysis

The *Sense of Being Affected* rating corresponding to the percentage of “Affected” responses was calculated for each level of facial pain expression (20%, 40%, 60%, 80%, 100%) and the two body conditions (*still*, *idle*). All statistical analyses were performed using Python libraries (LMFIT (Newville et al., 2014) and SciPy (Virtanen et al., 2020)) and JASP (JASP Team, 2019).

Firstly, an ANOVA with repeated-measures was performed on *Sense of Being Affected* rating with the intensity of facial expression (20%, 40%, 60%, 80%, 100%) and the body animation (*still*, *idle*) as within-subject factors. In case of violation of sphericity assumption Greenhouse-Geisser correction was applied. A paired t-test was then performed on *Sense of Being Affected* rating between the *idle* and *still* conditions, regardless the intensity of facial pain expression.

Secondly, a logistic function was fitted on *Sense of Being Affected* rating for each participant using the same formula as *Experiment 1*: $y = 1/(1+\exp(-(x-\text{PSE})/\text{JND}))$ in order to collect the Point of Subjective Equality (PSE) and the Just Noticeable Difference (JND) (see *Figure 2 and experiment 1 for details about this indices*). The *Sense of Being Affected* rating of four participants did not fit the logistic analysis, so they were excluded from analysis. Thus, the final sample for the analysis on the psychophysical variables (PSE and JND) was composed of 30 participants. Paired t-tests were performed on PSE and JND to compare the perception of facial pain expression in *idle* vs. *still conditions*.

3.3. Results

Repeated-measure ANOVA on *Sense of Being Affected* rating revealed a main effect of the facial expression intensity [$F(2.6,84.2) = 148.3, p < .001, \eta^2 = .65$], a main effect of the

body animation [$F(1,33) = 4.30, p = .046, \eta^2 < .01$] and a significant interaction between these two conditions [$F(3.3,110.3) = 3.04, p = .027, \eta^2 < .01$]. Post-hoc tests with Bonferroni correction revealed that the *Sense of Being Affected* increases significantly with the intensity of the facial pain expression except between the intensity 80% and 100% (see Table 2) (mean responses for the intensity 20%, 40%, 60%, 80%, 100% = 4.1%, 19.9%, 66.6%, 84.6%, 93.1% respectively; 95% CIs [-0.2%, 8.4%], [10.6%, 29.2%], [55.1%, 78.1%], [75.6%, 93.5%], [87.2%, 99.0%] respectively). Paired t-test revealed that participants reported significantly more often to be “affected” by the pain expression in the *idle condition* (mean proportion = 56.1 %, 95% CI [50.5%, 61.6%]) than in the *still condition* (mean proportion = 51.2 %, 95% CI [44.0%, 58.5%]) [$t(33) = 2.07 ; p = .046, d = .36$] (see Figure 6).

Paired t-test on PSE revealed a significant difference between the *idle* and *still conditions* [$t(29) = -2.15 ; p = .040, d = -.40$], which indicated that participants reported to be “affected” by the pain expression for a lower intensity of facial expression in the *idle condition* (PSE mean = 53.9 %, 95% CI [48.9%, 58.8%]) than in the *still condition* (PSE mean = 56.9%, 95% CI [51.0%, 62.8%]). Paired t-test on JND did not revealed a significant difference between *idle* (mean JND = 4.1%, 95% CI [2.4%, 5.8%]) and *still* (mean JND = 3.6%, 95% CI [2.1%, 5.2%]) conditions [$t(29) = 0.55 ; p = .59, d = .10$] (see Figures 7 and 8).

Table 2 – Pairwise comparisons for the perceived Intensity of the Facial Pain Expression

		Mean Difference	SE	t	Cohen's d	<i>p</i> bonf
100%	20%	0.890	0.040	22.344	3.832	< .001

	40%	0.732	0.051	14.357	2.462	< .001
	60%	0.265	0.047	5.588	0.958	< .001
	80%	0.085	0.029	2.966	0.509	0.056
20%	40%	-0.157	0.041	-3.885	-0.666	0.005
	60%	-0.625	0.059	-10.668	-1.830	< .001
	80%	-0.804	0.050	-16.012	-2.746	< .001
40%	60%	-0.468	0.049	-9.482	-1.626	< .001
	80%	-0.647	0.053	-12.164	-2.086	< .001
60%	80%	-0.179	0.032	-5.578	-0.957	< .001

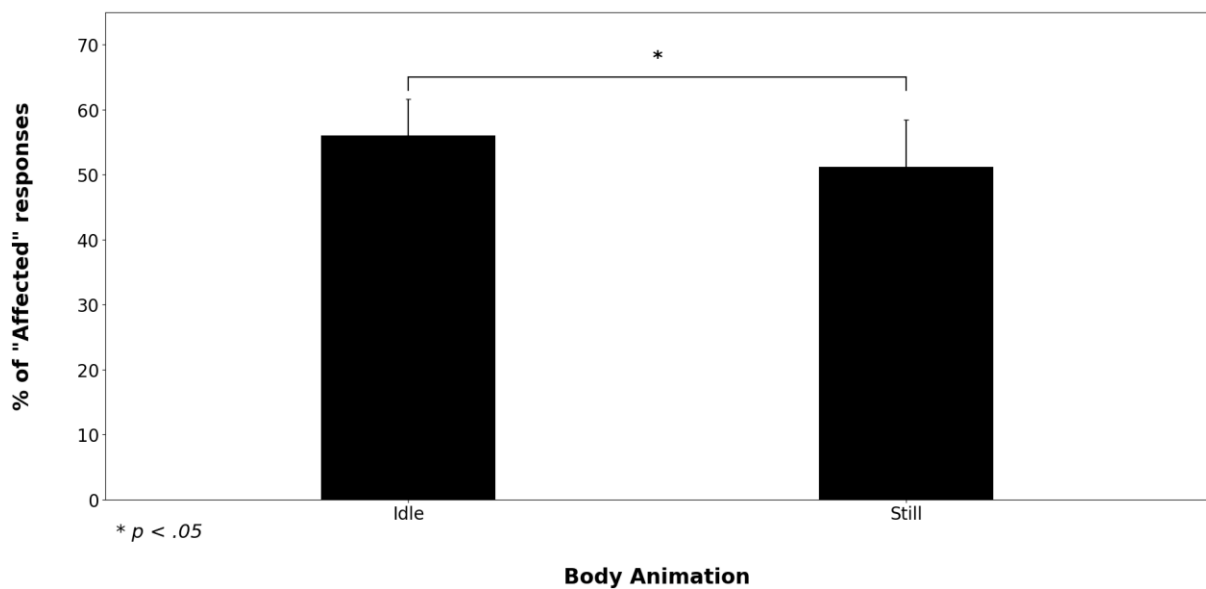


Figure 6 - Percent of "Affected" responses in the *still* and *idle* conditions taking all facial expressions intensities together. Error bars correspond to the confidence intervals at 95%.

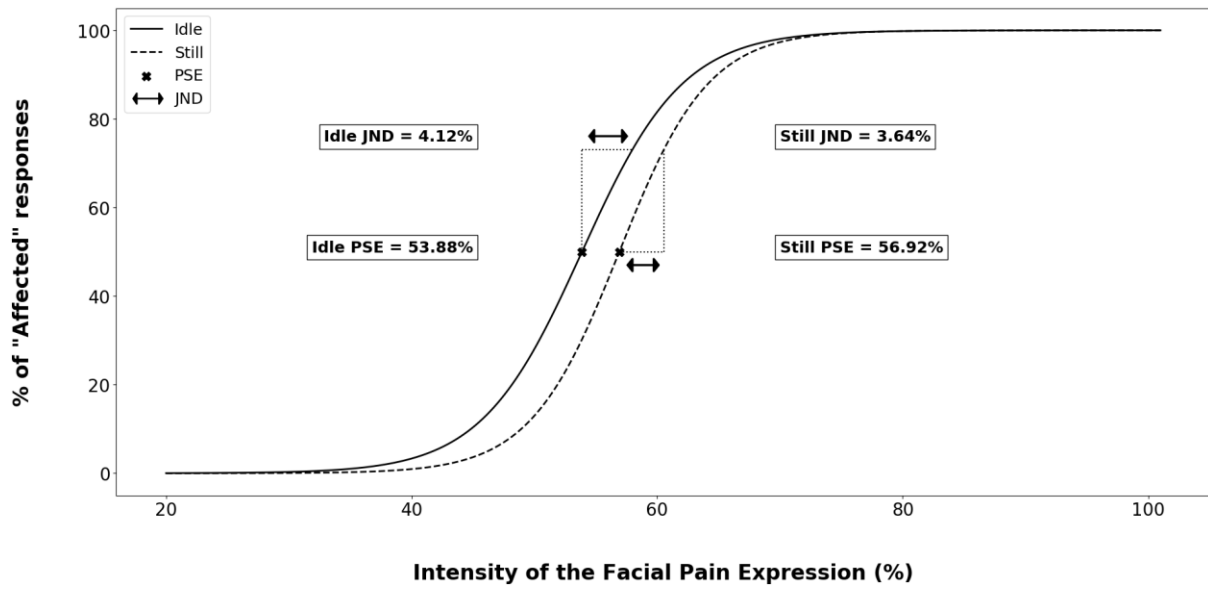


Figure 7 - Logistic modelling of “Affected” responses according to the facial pain expression intensity in the *still* and *idle conditions*. PSE and JND correspond to the mean of PSE and JND obtained from the modelling of each participant.

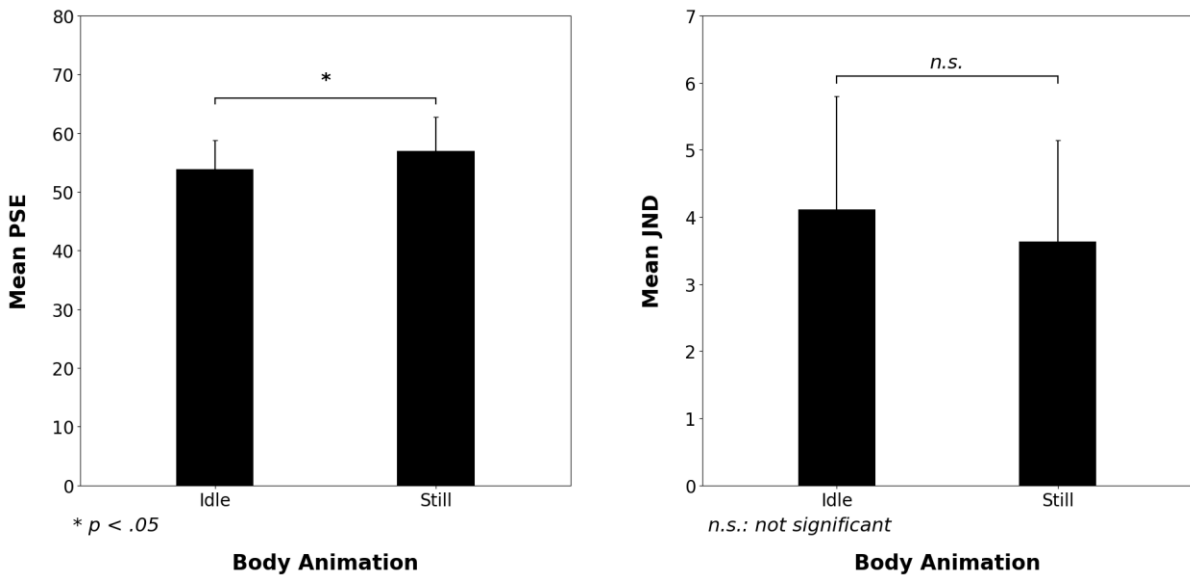


Figure 8 - Mean of PSE and JND obtained from the modelling of each participant in the *still* and *idle conditions*. Error bars correspond to the confidence intervals at 95%.

3.4 Summary

Results showed that participants became more affectively aroused by the CG character's pain expression in the presence of *idle motion* (natural human postural oscillations) compared with the *still condition*. Participants responded significantly more often "to be affected" (i.e. higher percentage of 'affected' responses) in the *idle condition* than in the *still condition*. Moreover, results revealed a significantly lower PSE in the *idle condition* compared to the *still condition*, indicating that a lower intensity of facial pain expression was necessary to affect participants in the *idle condition* than in the *still condition*. By contrast, the JND did not differ between the *idle* and *still conditions*.

In concordance with *experiment 1*, it is likely that the presence of postural oscillations make the avatar more human, and its emotion more genuine. Thus, participants would be more sensitive to its pain expression, as reflected by their enhanced *empathic response*. They would identify its pain as more intense, and would greater share its distress.

4. General discussion

The present study revealed the potential of idle motion, in particular naturalistic postural oscillations to strengthen behavioral realism of a virtual character, resulting in an increased empathy for its pain. By making the virtual character 'alive', its facial pain expression would be perceived more genuine, which may have enhanced the *empathic response* resulting from the perception of its pain, namely increasing perceived pain intensity (*experiment 1*) and affective sharing (*experiment 2*) when facing its facial pain expression.

These results confirm those previously observed by Treal and collaborators (2020), who had used the same platform. The authors showed that participants perceived the CG character's

facial pain expression as more intense and more believable when its trunk was animated with a subtle oscillatory movement. In the same vein, some studies in robots revealed that robot gestures during idle moments (i.e. moments when the robot does not perform a task) may enhance its anthropomorphism (Cuijpers & Knops, 2015) or its friendliness (Asselborn et al., 2017). The originality of the present work was the use of motion-captured postural oscillations, based on the bulk of evidence showing that the visual system is particularly sensitive to biological motion, which would be detected in an early and preattentive stage (Hirai & Senju, 2020 for a review and a recent theoretical model). The social function of biological motion in the context of voluntary action is well-documented (e.g. Alaerts et al., 2011; Dayan et al., 2018; Dittrich et al., 2016; Pavlova, 2012; Troje, 2013). To our knowledge, this study is the first to demonstrate its contribution in emotion perception research when kinematic doesn't contain socially relevant information (i.e. automatic movements such as postural oscillations). It is proposed that *idle motion* implemented naturally rather than mechanically would be critical to elicit the '*suspension of disbelief*', a term coined by de Gelder et al. (2018) to describe the acceptance that a CG character may feel emotion, although one keeps in mind that it is virtual. This hypothesis is supported by recent studies (Piwek et al., 2014; Williams et al., 2019), showing differences in emotional responses from participants when they observed an agent moving naturally or mechanically. Piwek and al. (2014) asked participants to judge the acceptability of different types of CG characters animated with biological motion or with the same motion distorted at different levels (mechanical motion). They showed that the implementation of biological motion enhanced the characters' acceptability compared to mechanical motion. Williams et al. (2019) showed that a human body moving naturally elicited both greater visual attentional engagement and automatic arousal (assessed by pupil size changes) compared with a human body moving mechanically.

Thus, the presence of biological motion in virtual characters might provoke an early unconscious identification of the virtual agent as a natural object (i.e. a human) rather than an artificial object. This early, pre-attentive identification would significantly influence the latter stages of its facial pain expression processing, and ultimately the sense of believability towards its pain experience. In other terms, natural human postural oscillations might be a critical component to trigger a more spontaneous emotional reaction (i.e. *empathic response*) towards pain expression of a virtual character. This view is in concordance with a recent hierarchical model of social perception (Teufel et al., 2019), supporting the idea that different sources of visual information would be initially processed, and then integrated in later stages of the visual system to shape a whole-person percept which would be consciously experienced. Nevertheless, future investigations are needed to explore this theoretical proposal, and in particular the idea of an unconscious primary categorization of an animated agent as human (i.e. natural object) due to the presence of biological motion.

Moreover, the positive influence of biological *idle motion* on the perception of a CG character's facial expression needs to be validated with other emotions (e.g. joy, disgust, fear, surprise, etc.) and demonstrated in more complex tasks including contextual and situational information (e.g. a narrative item before stimuli presentation, a contextual background, or even more complex scenarii). As pointed by scholars in affective neuroscience, the effect of context on other's emotion perception is piecemeal and not enough accounted for in the scientific literature (Barrett et al., 2019). In the same vein, some authors in affective computing endeavor the use of virtual settings (i.e. video games) in fundamental research, showing that participants rely also on contextual information, and even more than face expression to judge a CG character's emotion (Lankes et al., 2007; Lankes & Bernhaupt, 2011). Moreover, a recent study using a medical virtual system for nursing education questioned the impact of three levels of behavioral realism on nurse trainees' visual attention (assessed by gaze measures) when

interacting with a virtual patient to medically assess it, while its health condition was deteriorating (Volonte et al., 2018). The conditions of behavioral animation were : (A) *no animation*, i.e. the virtual patient was static; (B) *passive animation* with *idle motions* involving interactions with the environment (e.g. hand and head scratching, looking at TV); (C) *communicative (or conversational) animation* in which the virtual patient also gazed at participants, displayed communicative lip-synced speech, facial expressions and gestures, in addition to the passive animations). The authors observed that the type of animations did not significantly change visual attention. However, in this study, *idle motions* were artificially implemented using morphing (see another study of this group for the description of animation method : Wu et al., 2014). Thus, the issue concerning the influence of biological postural oscillations on the way one would empathize with a virtual person in ecological situations, and, its use to enhance the quality of human-machine interactions in an applied domain, remains entirely open.

5. Conclusion

The use of highly realistic CG characters to study emotion perception and social cognition offers the possibility to create an interactive, yet well-controlled interaction. *Idle motion* appears as a key component of behavioral realism. Surprisingly, this consensual stance is not supported by experimental evidence, except one recent study of our team, and the present work which demonstrated specifically the potential of biological postural oscillations to enhance empathy for pain expressed by a CG character. It was argued that motion-capture would be particularly relevant for idle movement animation, which is by essence a ‘by default component’, not designed to be interactive and flexible according to user’s responses. Overall, further research using contextualized settings (i.e. rich and life-like situations) will help to

elucidate the contribution of biological *idle motion* when perceiving emotion in a virtual agent, and more generally when interacting with it.

Declaration of competing interest

None.

CRedit authorship contribution statement

Thomas Treal: Methodology, Software, Formal analysis, Investigation, Data curation, Writing - original draft, Visualization, Funding acquisition.

Philip L. Jackson: Conceptualization, Methodology, Resources, Writing - review & editing, Supervision.

Nicolas Vignais: Methodology, Writing - review & editing.

Jean Jevrey: Methodology, Writing - review & editing.

Aurore Meugnot: Conceptualization, Methodology, Validation, Formal analysis, Writing - original draft, Supervision, Project administration.

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